Implementation of an Ocean Acoustic Laboratory at PMRF

Peter J. Stein
Scientific Solutions, Inc.
99 Perimeter Road
Nashua, NH 03063
phone: (603) 880-3784
fax: (603) 598-1803
email: pstein@scisol.com

James K. Lewis
Scientific Solutions, Inc.
4875 Kikala Road
Kalaheo, HI 96741
phone: (808) 651-7740
fax: (808) 332-5120
email: jlewis@scisol.com

Subramaniam D. Rajan
Scientific Solutions, Inc.
5907 106th Av NE
Kirkland, WA 98033
phone (425) 452-9005
fax (425) 452-9510
email: srajan@scisol.com

Award Number: N00014-00-D-0160/0002
http://www.scisol.com

LONG-TERM GOALS

The intended result of this effort is to enable a capability for an Ocean Acoustic Laboratory at the Pacific Missile Range Facility (PMRF). This includes a Tomographic Imaging (TI) System using the extensive PMRF range hardware, the computing power of the Maui High Performance Computing Center (MHPCC), and the high-speed data link connecting PMRF and MHPCC. The long-term goals include developing a plan for integration with other Navy programs. The capabilities identified and implemented in this effort will have extensive benefits to the Navy, ONR, DMSO (Defense Modeling and Simulation Office), Hawaii, and the ocean acoustics community in general. The Tomographic Imaging System will also lead to greater knowledge of the internal waves, internal tides, and internal temperature of the waters surrounding the Hawaiian Islands.

OBJECTIVES

The principal objectives for this project are as follows:

1. Develop the technology for performing tomographic imaging of the water column at PMRF using the existing bottom-mounted sources and receivers to provide the three-dimensional sound speed and water temperature characteristics of the region in near-real-time.

2. Integrate this directly-determined acoustic propagation and water temperature information with available satellite and meteorological observations and with hydrodynamic modeling of the ocean for an Ocean Acoustic Laboratory capability.

APPROACH

In recent years, considerable work has been done in developing acoustic tomographic methods for imaging the three-dimensional sound speed fields in the ocean. The classical approach to ocean acoustic tomography is based on measuring the travel time for a pulse traveling from a source to a receiver placed in the region of interest. This travel time is related to the integrated sound speed in the water over the acoustic path traveled. Each source-receiver pair gives a unique measure of the sound speed variations over a different path. The matrix of all travel times measured on the large number of source-receiver combinations can be inverted to determine the three-dimensional sound speed field.

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14. ABSTRACT
The intended result of this effort is to enable a capability for an Ocean Acoustic Laboratory at the Pacific Missile Range Facility (PMRF). This includes a Tomographic Imaging (TI) System using the extensive PMRF range hardware, the computing power of the Maui High Performance Computing Center (MHPCC), and the high-speed data link connecting PMRF and MHPCC. The long-term goals include developing a plan for integration with other Navy programs. The capabilities identified and implemented in this effort will have extensive benefits to the Navy, ONR, DMSO (Defense Modeling and Simulation Office), Hawaii, and the ocean acoustics community in general. The Tomographic Imaging System will also lead to greater knowledge of the internal waves, internal tides, and internal temperature of the waters surrounding the Hawaiian Islands.

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Furthermore, since sound speed is most strongly related to ocean temperature, the system can also provide an imaging capability of the three-dimensional temperature field.

The temperature data obtained from acoustic tomography will be assimilated into a hydrodynamic model of the ocean along with the data obtained from satellite and meteorological data. In this manner a high-resolution now-cast of the PMRF range can be developed.

WORK COMPLETED

Ocean Model

The hydrodynamic model used in this work is an adaptation of the model of Blumberg and Mellor [2]. This particular version of the Blumberg-Mellor model uses a semi-implicit solution scheme for solving for the sea surface height field [3]. The original implicit solver in [3] was modified to be capable of using relatively large time steps while avoiding numerical instability. Another modification of the original Blumberg-Mellor model is the use of a hybrid z-level vertical coordinate system discussed in [4] to minimize problems that can arise when using steep bathymetry and realistic temperature and salinity profiles.

The initial model simulations were performed in two stages. The first used a large-scale grid encompassing the island chain to determine the barotropic tide in the vicinity of Kauai. This island-wide model was run in a barotropic mode using the curvilinear-orthogonal grid. The model has a horizontal resolution from ~9.5 km around the open boundaries of the domain to approximately 3-4 km around the islands. The domain extends some distance offshore of the islands based on the barotropic scale related to the scattering of tidal-frequency waves by the islands [5]. The model bathymetry was interpolated from [6]. Simulations were performed for the S_2, M_2, N_2, K_1, O_1, and P_1 tidal constituents. The boundary values for the tidal constituents were obtained from the Oregon State University tidal model TPXO.3 [8]. These simulations provided sea level amplitudes and GMT phases for each tidal constituent to be used along the open boundaries of the Kauai model.

Using the sea level tidal amplitudes and phases from the island-wide domain, we then performed simulations utilizing a higher-resolution, fully three-dimensional model surrounding Kauai (Fig. 1). The grid spacing of the model is 2-3 km around the open boundaries of the domain to approximately 1 km around the shoreline of Kauai.
The model bathymetry was specified using topography from [6] augmented with higher resolution sounding data obtained from PMRF.

The three-dimensional simulations with the tidal forcing from the barotropic model were used to compare the observed tidal amplitudes and phases at Port Allen, Kauai, and Nawiliwili Harbor, Kauai with model-predicted amplitudes and phases. Based on the differences between the observed and model-predicted amplitudes and phases, a tuning procedure was followed to adjust the amplitudes and phases from the barotropic ocean model at the open boundaries in order to match the observed amplitudes and phases at Port Allen and Nawiliwili.

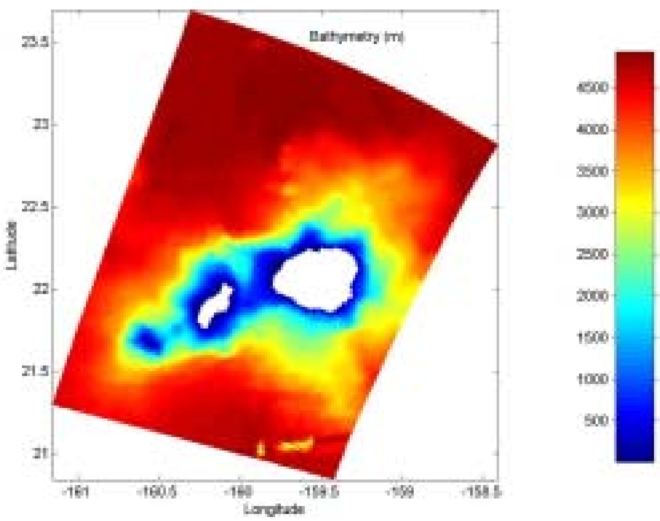

Fig. 1: Model domain for 3D model covering Kauai, Hawaii

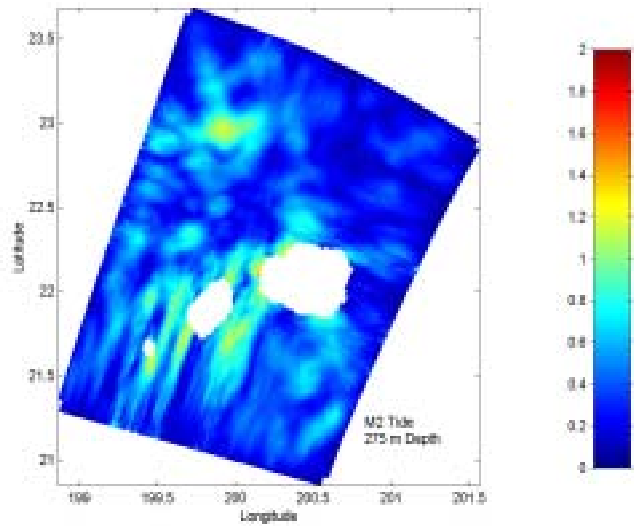

Fig. 2: Amplitude of temperature oscillations induced by M2 tide at 275 m depth

To provide as realistic forcing as possible, we utilized the open boundary condition (OBC) presented in [7]. An advantage of the OBC is that it can utilize other sources of sea level height information such as that available from the Navy's Modular Ocean Data Assimilation System (MODAS). As discussed in [7], an optimized approach is used for specifying the open boundary condition sea level elevations that utilizes the reference information as well as the physics of the model represented by the energy flux on the open boundary. The boundary conditions used for salinity and temperature are based on the input vertical structures of T and S. The model was adapted to input a background field of T-S values based on either a Naval Research Laboratory (NRL) monthly climatology for the Kauai domain or from a MODAS field of T-S values. The climatological T-S fields lack the realism of the MODAS fields in that MODAS utilizes observed satellite sea surface temperatures (SST's) and altimetry data to construct a first guess at a dynamic climatology that represents the mesoscale eddy field of the ocean. If the MODAS fields are not available, the model defaults to the climatological T-S fields provided by NRL.

Since strong, deep internal tides have been observed around the Hawaiian Islands [1], a simulation was performed to investigate occurrences of these tides around Kauai. The model was forced by the M_2 tide only (the strongest trigger for the internal tides), and the amplitude of the model-predicted temperature oscillations at each grid cell was used to characterize the occurrence and structure of the deep internal tides around Kauai. The amplitudes of the temperature oscillations due to the M_2 tide are shown in Figure 2. The largest amplitudes (1.2-2ºC) are found just off the west coast, a region in which PMRF has a shallow-water training range (SWTR).

An experiment was conducted from August 27-31, 2001 in which extensive acoustic and oceanographic data was collected. A simulation was performed for this time period using all tidal forcing plus the August climatology for the temperature and salinity structure of the water column. Figure 3 shows model-predicted temperature variations during part of the August 2001 acoustic experiment. The location of the predictions is approximately the center of SWTR in 492 m of water. Between 125 and 275 m, the tidally-induced oscillations are relatively strong.

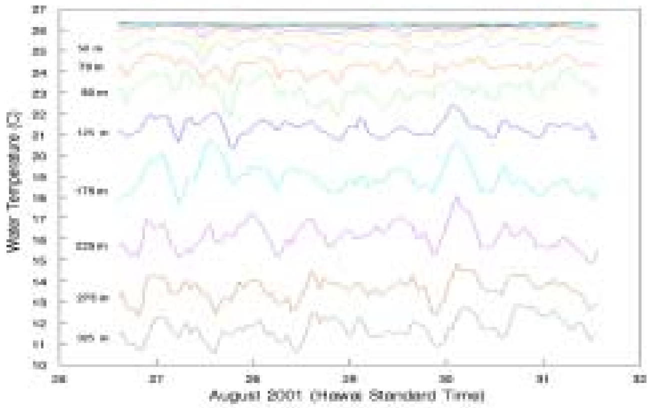

Fig. 3: Model predicted temperature variations within SWTR in ~490 m of water

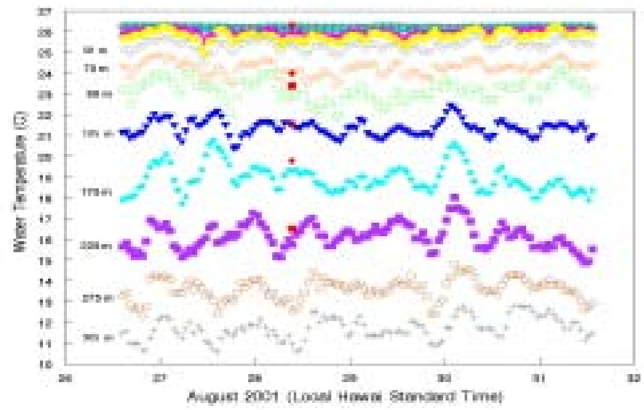

Fig. 4: Observed water temperature (red filled) overlaid over model predictions

An observed temperature profile from 50-225 m for the time and location in Fig. 3 is shown in Fig. 4. The model fits the observed temperatures quite well between 70-225 m.

Preliminary Acoustic Investigations

The Pacific Missile Testing Range has three ranges, namely BSURE, BARSTUR, and SWTR. The bathymetry varies in these ranges from 40 m in the SWTR to over 3000 m in the BSURE range. A total of 178 bottom mounted receivers and 15 bottom mounted sources are distributed in the range. The densest distribution of the receivers and sources (10 sources and 108 receivers) occurs in the SWTR range. An important issue that needs to be considered in studying the feasibility of implementing a tomographic imaging system is the resolution that is attainable with the spatial distribution of the sensors. The horizontal resolution was computed assuming straight-line path between the sources and receivers and it is shown in Fig. 5. The color bar shows the resolution in meters (from 0 to 20,000 m).

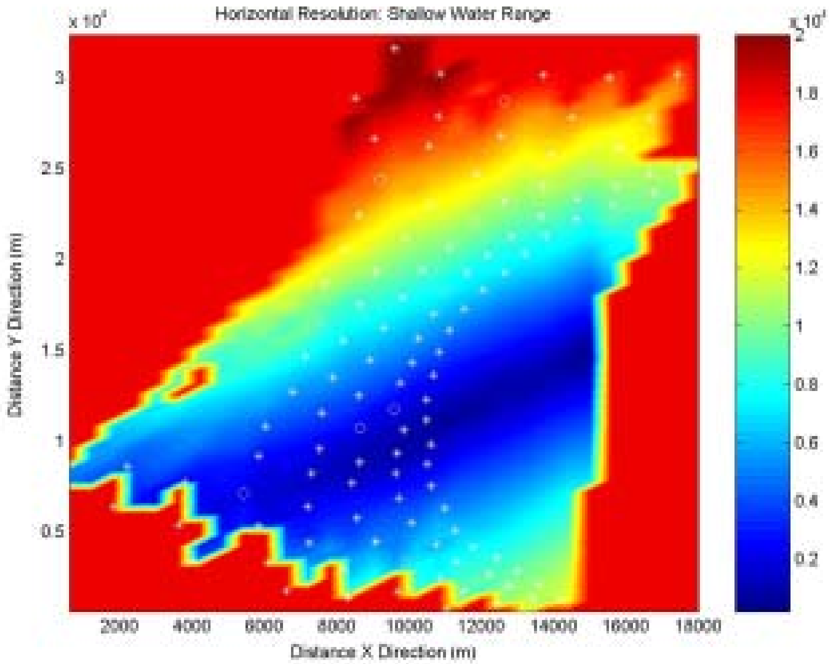

Fig 5.: Horizontal resolution obtainable over the SWTR using only acoustic tomography and considering only the straight-line path between source and receiver. The white dots are the locations of the SWTR receivers. Resolution might be substantially improved using multipath and assimilating the data into the ocean acoustic model.

It is observed from Fig. 5 that the resolution varies from less than 1 km (in regions where the density of rays connecting the source to receivers is high) to 12 km (where the ray density is low). The resolution in the vertical will depend on the number of stable ray paths between each source and receiver. Both the sources and receivers are bottom-mounted, and this will limit the number of detectable ray arrivals. The number of detectable rays will also depend on the bottom roughness, sediment properties, the source and receiver characteristics, bandwidth of the signal, and other properties. As mentioned above, a field experiment was conducted from August 27-31, 2001. The main objective was to assess the ability to detect and identify the arrivals as well as study the stability of the arrivals. A sample of the data obtained during this experiment is shown in Figure 6.

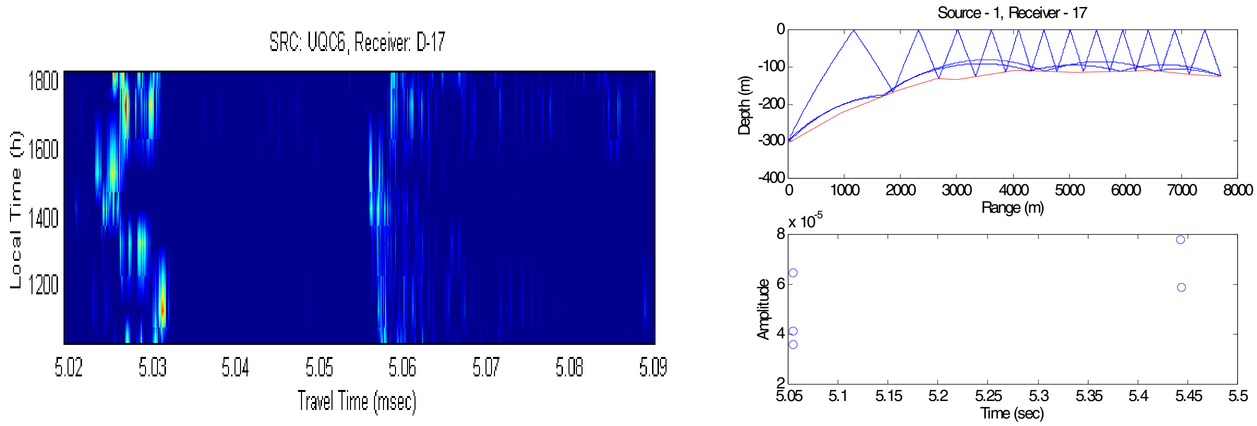

Figure. 6: The panel on the left shows the cross-correlation levels of transmitted and received signals out of one of the sources on the SWTR range (UQC-6) and one of the receivers roughly 7 km away (D-17). It shows the evolution of arrival time for the earliest arriving ray with respect to time. The panel on the right shows the ray diagram and the arrival times of the five rays for transmission from source UQC 6 to receiver D-17 obtained from ray trace models

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We note from the figure that the earliest arrival is easily identified. The figure also shows how this arrival time varies with respect to time from 1000 hrs to 1800 hrs. Our first look at the data indicates that it will be possible to detect and identify multi-path arrivals for the various source-receiver combinations. Further analysis of the data, which will indicate the feasibility of establishing an Ocean Acoustic Laboratory at PMRF, with a tomographic imaging system that gives adequate resolution, is in progress.

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